<u>Nuclear Waste Disposal Concepts – An Overview of the History of Radioactive Waste Management in the United States</u>

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The United States has been working to safely dispose of radioactive waste since the 1950's. Although deep geologic disposal has been the preferred option since a committee of the US National Academy of Sciences recommended it in 1957, other options have also been evaluated. Evaluation of alternatives to geologic disposal is not currently being pursued, with the exception of some ongoing research on transmutation.

The present effort dispose of spent nuclear power plant fuel and high-level wastes from defense activities is aimed at construction and licensing of a repository at Yucca Mountain in Nevada. Following a process defined in the 1982 Nuclear Waste policy Act, candidate repository sites were identified and successively reduced. In 1987, after the Department of Energy (DOE) had reduced the number of candidate sites to three, the US Congress selected Yucca Mountain for characterization. In 2002, the President approved the Secretary of Energy's site recommendation, and Congress approved the site recommendation over Nevada's veto. Current efforts are aimed at production of a license application, with a planned date for submission to the Nuclear Regulatory Commission of December 2004.

The U.S. program for disposal of spent fuel and high level waste grew out of an unusual alignment of interests between the nuclear power industry and environmental groups in the late 1970's and early 1980's. The industry wanted an early demonstration of waste disposal; this was seen as a necessary condition for resumption of nuclear power plant orders. Environmental and antiproliferation groups also wanted early disposal of spent fuel, to preclude reprocessing of spent fuel and the potential for proliferation of fissionable materials that might result.

Starting around 1970, the DOE began storing transuranic waste (TRU) produced in the weapons program, and most of the waste generated at the Rocky Flats site was moved to a DOE facility in Idaho. In 1980, efforts to construct and operate the Waste Isolation Pilot Plant (WIPP) began, and WIPP began operating in 1999 as the first U.S. deep underground geologic repository.

Unlike the Yucca Mountain site, the WIPP site does not contain potable water; this was important to achieving regulatory concurrence that the facility could operate. In contrast to Yucca Mountain, WIPP is known to contain natural gas and oil resources, so the likelihood of future human intrusion into the repository has been a central issue in its performance analyses.

<u>Nuclear Fuel Cycle</u>

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The nuclear fuel cycle creates the spent fuel and high-level waste that repositories must be designed to accommodate. This presentation provides an overview of various fuel cycle options, including once-through and closed fuel cycles, discussing the major characteristics of the various waste streams that emerge. As national repository programs progress, for example the Yucca Mountain Project in the United States, an increasingly detailed understanding of repository performance, licensing, and operations is emerging. This understanding can in turn feed back to the design of advanced fuel cycles. Advanced fuel cycles have the potential to favorably impact repository performance and operations. Therefore this presentation also discusses the options provided by advanced fuel cycles to modify waste decay heat output, optimize waste volumes and leach resistance, and to alter and reduce inventories of long-lived radionuclides. The economic challenges of various fuel cycle options are then reviewed, and the potential for advanced fuel cycles to couple to repository optimization are summarized.

REGULATOR’S PERSPECTIVE ON JUDGING THE SAFETY OF A PROPOSED REPOSITORY OVERVIEW

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This paper presents the regulator’s approach in the United States, for judging the safety of a proposed geologic repository for disposal of radioactive waste. In the U.S., the Nuclear Regulatory Commission (NRC) is responsible for setting rules that are protective of the public health and safety, and making decisions on whether to approve any license application of the U.S. Department of Energy (DOE). The NRC’s approach, while specific to the U.S., includes many elements that are common to all regulatory approaches for radioactive waste disposal.

<u>THE U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD</u>

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In 1987, as part of the Nuclear Waste Policy Amendments Act, the U.S. Congress established the Nuclear Waste Technical Review Board as an independent federal agency. The Board is charged with evaluating the technical and scientific validity of the Department of Energy's efforts to develop a system for disposing of high-level radioactive waste and spent nuclear fuel. The Board is composed of 11 experts who serve part-time for a four-year term. It is required to report its findings and recommendations to the Congress and to the Secretary of Energy at least twice a year.

The presentation describes the Board's structure and organization. It examines the set of scientific and technical issues that the Board has addressed of the years. These include the reliability of very long-term geologic predictions, the assessment of water flow and radionuclide transport in fractured, unsaturated rocks, predicting corrosion rates and processes at high temperatures, and extrapolating long-term materials performance.

The presentation also reviews some of the Board's major recommendations and the Department of Energy's responses to those recommendations. It discusses the Board's letter to Congress and the Secretary of Energy issued in January 2002. Legislators used this letter when they were considering whether to overturn the State of Nevada's veto of the President's recommendation that the Yucca Mountain site be developed as a repository. Finally, this presentation considers the role of the Board as the Department of Energy prepares an application to the Nuclear Regulatory Commission to construct that repository.

<u>**Project Management in a Regulatory Environment**</u>

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Part 1. Short- and Long-Term Planning

A long-term program such as development of a geologic repository requires the implementation of good management practices that can sustain the program and demonstrate progress toward the ultimate goal of disposal of nuclear materials. Prior to beginning work on the program, the management organization should establish primary goals or milestones and identify logical points for evaluation of progress. This will provide the framework for development of a logic-driven schedule for the necessary work.

Part 2. Conducting Work

All work on the program should be allocated to an element of the Work Breakdown Structure. If the work must be done in accordance with certain standards, those must be identified. If there are certain things that must be included in the product, those must be stated. Even true “level of effort” work, such as administrative support, should be accounted for. The costs of doing the work can serve as a measure of overall progress of the program. The product and deliverable descriptions and criteria are a form of contract between the administrator and the scientist or engineer to define what is expected and to assure that all the work required is appropriately defined and funded.

Part 3. Communicating with External Parties

Work on a Geologic Disposal system is of interest to a number of diverse parties. Interactions and discussions should be planned with the regulatory and oversight bodies that have jurisdiction over the process. The general public should also be included in the decision-making process. This means that a certain amount of the time of scientists and engineers should be set aside (and appropriately funded) to meet with external parties. In developing the plan of work, consideration should be given to when information will be mature enough to share with the public and engage the regulatory agencies in discussions of results and progress toward demonstrating compliance with the standard.

Part 4. Maintaining a Record

The results of decisions and basis for changes to the program must be documented in sufficient detail to justify the action. A presence of a repository has the potential to impact future generations that should be aware of the knowledge available to the constructors and the reasoning that led to particular decisions. Records systems should be implemented that assure traceability and transparency of results, conclusions. The information collected in the course of site characterization is also a valuable scientific resource that should be disseminated as openly as possible.

INSTITUTIONAL ARRANGEMENTS FOR MANAGING RADIOACTIVE WASTE: DO THEY MATTER?—SHOULD WE CARE?

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Today the biggest challenges to waste disposal programs are societal in nature, so says a study panel sponsored by the U.S. National Academy of Sciences. This paper is designed to explore the implications of that statement. It describes what type of issues fall into the broad category "organizational, institutional, and social." It discusses why those issues have become increasingly important. It considers a variety of approaches taken in western democracies to address those issues. It explores the special issue of public trust and confidence. Finally, the paper asks the question, "Where do we go from here?"

Several conclusions can reasonably be drawn from the analysis presented in the paper.

- A sense of technological optimism that pervading thinking about radioactive was early on has had serious negative consequences presently.
- Designing and implementing effective institutional arrangements can be as pivotal to the success of a repository program as designing and producing effective waste packages.
- There are many factors inherently associated with radioactive waste management that make designing and implementing those institutional arrangements very difficult.
- National programs can follow many paths that are equally successful (or unsuccessful). Experiences in other countries do provide heuristic insights but not definitive prescriptions.
- • Public trust and confidence maybe

Site Screening and Selection

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Robert Murray – Booz Allen Hamilton, Inc.

Historical review of the United States' high-level radioactive waste disposal program over the past 50 years provides a context for examining site screening and various forms of siting criteria. The U.S. identified three possible approaches to exploration for potential sites. The first was to select suitable host rock type(s), determine their distribution and then screen successively smaller areas. The second involved screening sites based on previous land use, such as government lands already used for radiological activities. The third focused on geohydrologic conditions and selected successively smaller land units with favorable properties.

Essential to successful site screening is a systematic process that provides a defensible step-by-step decision process. Establish roles, responsibilities, and authorities for regulators, stakeholders, and oversight entities. Involve government representatives, the technical community, and the public. Define transparent and traceable documentation of data, methods, results, and decisions. Consider geographic diversity and equity in addition to technical factors. Consider the technical feasibility in terms of constructability and availability of infrastructure before committing significant resources to a potential site.

Four sets of siting criteria have been developed in the U.S. The first of these was the Site Performance Criteria issued by the National Waste Terminal Storage Program (NWTS). The second was promulgated as the Nuclear Regulatory Commission's (NRC's) Siting Criteria that were part of their licensing requirements at Title 10, Part 60 of the Code of Federal Regulations (10 CFR Part 60). The third was the Department of Energy's (DOE's) General Siting Guidelines at 10 CFR Part 960 and the fourth was the DOE's Yucca Mountain Site Suitability Guidelines at 10 CFR Part 963.

The NWTS criteria and the General Siting Guidelines focused more on screening diverse potential sites and identifying sites for further consideration. As such, they tended to specify conditions that would include or exclude potential sites during the decision process. The NRC's Siting Criteria sought a combination of favorable and potentially adverse conditions that a site could exhibit as part of the overall licensing requirements for a selected site. DOE's Site Suitability Guidelines adopted an integrated total system approach, consistent with revised NRC licensing requirements, to evaluate the suitability of the Yucca Mountain site for development of a repository. Each of these criteria sets ultimately focused on evaluating performance at a system level.

In formulating siting criteria, consider all pertinent aspects of repository siting, licensing, construction, operations, and closure. This involves the environmental, societal, and transportation implications as well as the geo-technical aspects of a potential site. Siting criteria should be consistent with established national and international guidance and regulations. Consider the applicability of the criteria, how they would be used for evaluation of individual sites *versus* comparisons among multiple sites. Separate technical criteria should be amendable to system-level evaluations. The primary attribute of a repository system is the ability to isolate wastes for long periods of time.

Preliminary Site Characterization

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Introduction.

Once a potential site for a geologic repository has been selected, work must focus on developing a sufficient understanding of the geology and environment. The type and extent of testing will depend on the criteria that will be used to determine whether the site and the engineered barriers will safely isolate waste. This section describes early phases of the site characterization process.

Part 1. Identification of Regulatory Requirements

Prior to beginning any site characterization activities, an evaluation of the regulatory requirements should be conducted to answer some simple questions. What are the criteria that must be addressed to show that the site can safely isolate waste? What key issues must be resolved to show that the criteria have been met? Strategies for demonstrating compliance will be based on the answers to these questions. A testing program will evolve as the key issues are further decomposed into a series of issues or questions that can be addressed through discrete testing activities.

Part 2. Develop conceptual models

In parallel with the regulatory analysis and based on knowledge of the site gained in the screening process, develop a general conceptual model and sub-models of the site. This should take into account: geology (structure, mineralogy, petrology, surface processes, potential for seismic or volcanic events, etc), hydrology (surface, groundwater), climate, and environmental factors. Identify key model parameters that respond to the regulatory issues or must be understood or quantified in order to develop confidence in the models. Develop testing strategies and plans to acquire the needed data or information.

Part 3. Strategies for Demonstrating Compliance

The conceptual model and the analysis of regulatory requirements are used to make a preliminary identification of the barriers to radionuclide migration that could be relied on in proving the site can safely contain radioactive waste. An expected level of performance can then be provisionally allocated to each potential barrier. As information is developed about the site, and the engineered system planned to complement it, the degree to which any one barrier contributes to overall performance may change.

Part 4. Early investigations

At the beginning of the site characterization process, investigators will rely primarily on existing information to develop conceptual models and focus on areas for testing. Plans may already be underway or developed for an underground testing facility. Prior to breaking ground initial, surface-based, investigations should focus on detailed geologic mapping, trenching and drilling to provide sufficient detail to better define the underground facility. Surface investigations will also provide data with greater spatial (vertical and horizontal) variability than the underground facility. Investigations should also extend well beyond the site boundaries to support understanding of, for instance, regional flow systems and tectonic regimes, surficial processes, and climatic changes. Test plans should ensure that all requirements for the testing are identified, and that a clear relationship exists between the proposed test and issues that need to be resolved. Beware of over-planning.

Part 5. Use of Performance Assessment Models

Numeric models, both Total System Performance and Sub-systems, should be developed in parallel with site investigations. Early models will be simplistic representations of conditions and processes at he site. Data from site investigations will be used to further develop and refine the models. As the models mature, they should be used as predictors of conditions/phenomena. This iteration between models and investigations will allow the program to focus on areas needing further analysis or investigation, and refine or revise its definitions of barriers important to isolation of waste.

<u>**Preliminary Site Characterization**</u>

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The Underground Research Laboratory constructed in Canada provided a means of developing the techniques, technologies and capabilities to conduct both a preliminary and detailed underground site characterization of an undisturbed granitic rock mass. The URL site evaluation program involved characterization of the rock mass, groundwater flow systems and groundwater chemistry of the geologic environment. This used both surface and underground measurements as construction and operation proceeded. The underground program involved studies of the geologic barrier and of the engineered components of the sealing system.

The site characterization process involved development of then refinement of a general geologic model for the site. Major fracture zones and geologic features were identified and used to begin to develop a hydrogeologic conceptual framework for the site. The site evaluation then progressed into development of a geo-mechanical conceptual model for the site and identification of unique site characteristics. The development of a site model was accompanied by the conduct of a monitoring and testing program that was intentionally generic in nature and that could be readily adapted to any other similar geologic medium.

The conditions encountered at the URL highlighted the need for robust instrumentation and the physical limitations of a number of conventional instruments. The ability to deal with high differential rock stresses, high groundwater pressures and aggressive groundwater was a necessity in the URL environment (and also elsewhere in the Canadian Shield). This has required the development of new instruments for use in the type of deep geologic environment anticipated in a granitic rock mass.

A deep geologic repository also requires a very different level of care in excavation technique relative to that of most normal mining or engineering constructions. As the primary goal of a deep geologic repository is to keep the waste isolated and limit its ultimate migration the rock mass used should be disturbed as little as possible in order to maintain its isolating capability. Special careful drill and blast techniques were developed and mean to monitor the disturbance caused by this excavation were also developed at the URL.

<u>Geoscience Knowledge Integration</u>

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This session focuses on how data and information developed as part of a geoscientific characterization program can be integrated into a comprehensive management process that emphasizes the output of knowledge and wisdom. Ultimately, this knowledge and wisdom is used more effectively for decision making at all levels of an organization. The approach is based on a method developed as part of an integrated regional hydrogeologic investigation of the Death Valley regional ground-water flow system for the Yucca Mountain Project. The study was funded by many different stakeholders within the region and involved numerous earth and environmental scientists from government, academia, and private sector.

The approach emphasizes the concepts of knowledge integration and the treatment of data, information, knowledge, and wisdom as the logical progression of products required for decision making. The instructors will provide an overview of the tools required for implementing knowledge integration in a geoscience enterprise, including improving knowledge interactions, formalizing collaborative processes, and using enabling information technology. Also, the instructors will discuss how these tools may be incorporated into structured decision processes for increased efficiency and effectiveness in the enterprise.

A detailed case study is presented outlining the steps taken to improve technical and spatial data management, three-dimensional hydrogeologic framework modeling, and ground-water flow modeling activities for a group of geographically dispersed scientists in the southwestern United States. A demonstration will be given of the knowledge integration environment used in the study.

Discussion will focus on the applicability of the methods described to other waste isolation programs.

<u>**Natural and Man-Made Natural Barriers**</u>

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The Canadian Concept for deep geologic disposal in a crystalline rock mass requires that means to characterize and assess potential repository sites be developed and qualified. The Canadian URL provided a location where a previously undisturbed granitic rock mass could be assessed using a wide range of intrusive and non-intrusive techniques. The materials recovered in the course of the construction and characterization process could be assessed using laboratory testing. The results of in situ and laboratory tests and the predictions for rock performance and opening stability developed using a variety of numerical modelling approaches could then be compared and used to better refine the predictive capacity of numerical models for rock performance.

The changes in rock stability and the degree of disturbance/damage induced by the excavation of large openings in a rock mass having very high differential stresses was investigated at the URL. Excavation techniques and design approaches were proposed and tested at the URL and allowed for the development of a technology that can limit excavation-induced damage in granitic rock.

The URL also provided a location where remote monitoring using acoustic emission and micro-seismic technologies could be tested, calibrated and routinely used to monitor the degree of immediate and long-term rock disturbance around large openings excavated through an intact rock mass. This technology also allows for non-intrusive monitoring of a rock mass.

The behaviour of the disturbed rock mass has been described using a variety on numerical modelling tools including: Linear and non-linear continuum models were found to be inadequate to describe excavation responses. A combination of other approaches such as linear-elastic models, (thermo-poroelasticity) and Discrete Element Models such as PFC were developed or applied and found to provide a good means of predicting the onset and severity of excavation response.

<u>**Engineered Barriers**</u>

David Dixon
AECL

The Canadian approach to permanent disposal of used fuel as outlined in AECL's Environmental Impact Statement is to construct a repository in a crystalline rock mass somewhere within the Precambrian Canadian Shield. The un-reprocessed used fuel would be installed in mechanically robust and corrosion-resistant metal containers.

These containers would have a design life in excess of 100,000 years. Beyond these containers the repository would contain a series of compatible engineered barriers that would ensure that any contaminants released would be kept isolated for a sufficiently long time for them to pose no risk to the biosphere.

Development of the engineered barriers system was the result of an exhaustive screening process for both component durability and component compatibility with other sealing system components. These barriers need to function under environmental conditions where a combination of elevated temperature, high rock stresses, high groundwater pressures, chemically aggressive groundwater and reducing conditions all exist.

Each engineered barrier component within the sealing system was developed by following a stepwise process:

1. Screen a wide variety of potential materials.

2. Identify one or more candidate materials.

3. Conduct fundamental characterization on candidate materials.

4. Develop a set of potentially workable materials for use as references inconduct of the performance assessment.

5. Develop and test a variety of numerical models for use in developing performance assessment tools for application at an actual repository site.

6. Conduct an optimization program to develop formal specifications for materials and a toolbox of sealing technologies for use in a range of potential repository environments.

The performance of a range of field-scale installations of sealing materials were examined in the URL. These installations allowed the effects of scale and environment to be evaluated and the performance of specialized monitoring equipment to be assessed.

Regulatory Aspects of Engineered Barriers in the U.S. Program

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The Nuclear Waste Policy Act, as amended (NWPA), authorizes the U.S. Nuclear Regulatory Commission (NRC) to promulgate technical requirements and criteria that provide for "…the use of a system of multiple barriers in the design of the repository…" (NWPA Section 121(b)(1)(B)). The NRC's current licensing regulation (10 CFR Part 63) sets forth these criteria.

The NRC explains the term "multiple barriers" in Section 63.102, Concepts, to mean both natural and engineered barriers. Together these two barrier types address the uncertainties in characterizing and modeling individual barriers. The Postclosure Performance Objectives (Sec. 63.113) require that the engineered barrier system (EBS) be designed so that, working in combination with natural barriers, radiological exposures are within the regulatory dose limits.

The specific requirements for Multiple Barriers (Sec. 63.115) call for the identification of the design features of the EBS that are considered important to waste isolation. DOE must describe the capabilities of the barriers and provide the technical basis for this description.

The requirements for the Postclosure Performance Assessment (Sec. 63.114) include the provisions for information on the design of the EBS used to define parameters and conceptual models. DOE must account for uncertainties and variabilities in parameter values and provide the technical basis for parameter ranges, probability distributions, or bounding values. DOE is to consider alternative conceptual models that are consistent with available data and current scientific understanding. Then, the technical basis for inclusion or exclusion of degradation, deterioration, or alteration processes of the engineered barriers and the technical basis for models used in the performance assessment must be provided.

The Performance Confirmation Program (10 CFR Part 63, Subpart F) requires that DOE provide data that indicate whether engineered systems and components are functioning as intended and anticipated. This program includes in situ monitoring, laboratory and field testing, and in situ experiments. However, the program must not adversely affect the ability of the engineered elements of the repository to meet the performance objectives. Specific provisions of performance confirmation related to the engineered barriers include Design Testing (Sec. 63.133) and Monitoring and Testing of Waste Packages (Sec. 63.134).

The fundamental regulatory change regarding engineered barriers from NRC's general repository licensing requirements at 10 CFR Part 60 to the Yucca Mountain site-specific rule at 10 CFR Part 63 has been the adoption of a performance-based, risk-informed approach. Part 60 set forth specific sub-system requirements such as substantially complete containment within waste packages for 300 to 1,000 years after permanent closure. Part 60 also established specific design criteria for the repository and waste packages. In contrast, Part 63 now emphasizes total system performance and allows DOE to allocate barrier performance toward meeting system-level performance objectives, so long as DOE can provide the technical bases for analyses and defend them in licensing proceedings.

Underground Exploratory Studies
The Yucca Mountain Exploratory Studies Facility

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Introduction

The Exploratory Studies Facility at Yucca Mountain is a two tunnel, thirteen alcove complex of large diameter excavations that are used for scientific studies and collectively as a demonstration project for a spent nuclear fuel and high-level waste repository. The Office of Civilian Radioactive Waste Management, U.S. Department of Energy, developed the Yucca Mountain Exploratory Studies Facility at the potential site of a repository. The Yucca Mountain Exploratory Studies Facility is located on the western margin of the Nevada Test Site approximately 160 km. northwest of Las Vegas in the State of Nevada, U.S.A. Due to the proximity of the Nevada Test Site, all the facility property is under the control of the United States Government. The physical setting is that of a north-south trending low ridge in Mid-Late Miocene welded tuff of the Topopah Spring Tuff Formation. The area is quite arid, with annual precipitation averaging approximately 15 cm., and sparsely populated in the immediate vicinity of the facility.

The Exploratory Studies Facility will be operated for many decades providing a dual purpose as a test bed for future studies and access for nuclear waste emplacement. Knowledge gained from the current testing and opportunities for future studies and sharing of technologies with the international community will be enhanced by current membership in the International Atomic Energy Agency (IAEA) Network of Centres of Excellence, Training in and Demonstration of Waste Disposal Technologies in Underground Research Facilities.

Facility Excavation and Testing

An underground facility at Yucca Mountain to study the natural physical processes of the site was first conceived in the early 1980's and evolved from a twin vertical shaft configuration to an underground complex of galleries and alcoves with access to the target repository horizon accomplished through long inclined ramps. Following several years of geotechnical investigations to support the facility construction, the first large diameter ramp tunnel was started in 1994. The 7.62 meter (25 ft.) diameter north ramp was initiated with drill and blast construction to prepare for the launch of the tunnel boring machine. Concurrent with excavation, initial measurements of rock response were collected, alcoves constructed, and test equipment installed. Due to the anticipated dry nature of the rock mass particular attention was paid to the construction water usage and initial observations and testing that would detect the presence of free water in the excavation. Tunnel excavation was continuous and resulted in a 2187 meter (7108 ft.) long inclined north ramp, a right angle turn to the left, a 4238 meter (13,774 ft.) long nearly flat main, another right angle turn to the left and a 1452 meter (4,719 ft.) long inclined south ramp to daylight at the south portal with a total of 7877 meters (25,600 ft.) excavated. Eleven testing alcoves were initially constructed and fitted with scientific test equipment. In

1998, a nearly 2700 meter (8,775 ft.) long, five meter (16 ft.) diameter cross drift was excavated to expose the full extent of the intended repository horizon and is now being supplemented with additional alcoves and testing equipment. Today, we have well over 10,000 linear meters of excavated rock exposure in ramps, galleries, and alcoves with over 20 major experiments either completed or in progress.

Characterization Results compared to Predictive Calculations

The major areas of inquiry for understanding the physical processes at Yucca Mountain have been those associated with the presence and flow of water, and the effect of thermal loading of nuclear waste on processes associated with the hydrology, mechanical stability, and chemical change of the repository environment. We collectively term these effects coupled processes.

Key to confidence building was the development of pre-test calculations of the results expected from the experiments. Although we have conducted numerous experiments to look at essentially all aspects of process behavior in the underground facility, the largest and most complex, the Drift Scale Thermal Test, was designed to develop a better understanding of the thermal, mechanical, hydrological, and chemical coupled processes. The Drift Scale Test involved the in-situ heating of approximately 25,000 m3 of extensively instrumented rock mass. The temperature of the rock mass was raised from 23 C ambient to 200 C over a period of four years. The rock mass is now in a cool-down stage. The test was conducted in a full-scale drift with nine, heated, simulated waste canisters. Although not a true analogue of a repository, the simulated size and configuration of the test drift was a demonstration of how a typical repository emplacement could look. Other major tests include water seepage and percolation studies, the effects of fractured rock and faults on water movement, and excavation effects of developing the large diameter openings under ground.

To date, we have determined that unsaturated air-fall geologic units above the proposed repository horizon dampen water flux and that water moves very slowly through the proposed repository horizon largely along fractured flow paths. In addition, we have learned that very small amounts of water, if any, will seep into the underground openings at current and future climate states. We also know that the heat of the radioactive waste and spent fuel will drive off water during the thermal pulse, but then return as reflux. The chemical composition of this reflux water is not expected to significantly corrode the engineered barrier system during the 10,000-year regulatory period. Radionuclides that are transported from the deteriorating waste packages long after the regulatory period will be retarded and sorbed by interaction with zeolitized tuffaceous geologic units and alluvial units in the downstream flow path away from the proposed repository site. Measurements of rock properties in both the ambient and thermally stressed state do not indicate significant structural deformation problems will occur in the underground facilities. Many of our predictive models of physical processes compare well with test measurements and give us confidence that we do in fact understand the important aspects of the physical processes important to the Yucca Mountain repository system.

Future Activities

Testing in the underground facility at Yucca Mountain will continue through the licensing process to increase confidence, strengthen our technical basis and address parameter and process uncertainties. Additionally, the Nuclear Regulatory Commission at 10 CFR 63 Subpart F (see reference 1) requires that a performance confirmation program, a long term program of in-situ monitoring, field testing, and experimentation, be described as part of the License Application and implemented as a condition of the license to construct and operate.

Network Activities

As we move forward to licensing and eventual construction of the Yucca Mountain facility, it is important for us to share knowledge derived from our studies. Additionally, we desire to continue to utilize the facility, which was constructed at considerable cost and will not be fully operational as a repository until the time of waste emplacement currently scheduled for 2010. As such, Yucca Mountain has become a member of the International Atomic Energy Agency Network of Centers of Excellence for training in and development of waste disposal technologies. The utilization of the Yucca Mountain Exploratory Studies Facility as an underground research facility, combined with the capabilities of the U.S. Department of Energy National Laboratories, will provide an opportunity for valuable experience and training in the siting and site characterization aspects of nuclear waste management.

Additional References

1. 1. U.S. Nuclear Regulatory Commission, 2001, 10 CFR Part 63, Disposal of High-Level Waste in a Proposed Geological Repository at Yucca Mountain, Nevada.

2. 2. CRWMS M&O, Geology of the Exploratory Studies Facility Topopah Springs Loop, BAB000000-01717-0200-00002, REV 01, Report developed for the U.S. Department of Energy (1998).

3. 3. Yucca Mountain Site Description (available on OCRWM Website).

4. 4. Yucca Mountain Science and Engineering Report (available on OCRWM Website).

<u>**Underground Exploratory Studies**</u>

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The Canadian Underground Research Laboratory (URL) has had a wide range of geosphere and engineered barriers exploratory, characterization and performance studies conducted at it. The URL has been used to develop the capability to:

- Predict the projection of surface features into the subsurface environment.
- Characterize an undisturbed rock mass.
- Determine rock response to excavation.
- Develop an understanding of contaminant transport through rock masses.
- Understand the coupled Thermal-Mechanical-Hydraulic behaviour of a crystalline rock mass.
- Demonstrate sealing system construction and conduct in situ tests of sealing system performance.
- Conduct long-term monitoring of both the rock mass and sealing systems installed within it.Within the underground exploratory and characterization program conducted at the URL and intended to provide the basis for conduct of a site selection and characterization program have been the following activities:

Hydro-geology / geochemistry:	- Flow system monitoring
	- Groundwater sampling
Geology / Geophysics:	- Mapping and photography
	- Borehole drilling and logging
	- Radar and crosshole ultrasonics
	- Acoustic emission / microseismic monitoring
Geomechanics:	- Rock properties testing
	- Fracture properties testing
	- In situ stress determinations
Excavation Response:	- Mechanical and hydrogeological

Careful Blasting: - Blast design and quality control.

In addition to the underground characterization program a complimentary program examining a large number of tests have been conducted to establish the impact of excavations on the local geosphere and the sealing system components and include:

SOLUTE TRANSPORT

- Solute Transport in both Moderately and Highly Fractured Rock
- *In Situ* Diffusion Experiment
- Quarried Block Fracture Migration Experiment
- Connected Permeability Tests

EXCAVATION RESPONSE

- Mine-by Experiment
- Excavation Stability Study

SEALING EXPERIMENTS

- Grouting of Fracture Zones
- Buffer/Container and Isothermal Experiments
- Composite Seal Experiment
- Tunnel Sealing Experiment

Numerical Modeling and Repository Design

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In the design of a repository for spend nuclear fuel there must be an interactive process between numerical modeling, physical testing and engineering design, all of which ultimately feeds into the performance assessment stage of concept development or facility design. Specific numerical models for material response and various physical processes models are required for support of both engineering design and performance assessment. These models:

1. Provide input directly to performance assessment

2. Are used to confirm the appropriateness of simplified performance assessment models

3. Aid in understanding important phenomena that might affect system performance

4. Assist in developing design criteria for construction and engineered barriers

5. Provide means for correlating single point measured responses (i.e., pore pressure, displacement, acoustic emission) from monitoring instrumentation with possible events occurring within a sealing system.

The development of the various supporting numerical models and PA codes cannot be accomplished independent of a means of physically testing and calibrating their outputs via a large-scale field demonstration where natural processes can be allowed to occur. In many cases numerical models, their input parameters or boundary conditions needed to be adjusted in order to better reflect the reality of field performance.

A wide variety of numerical modeling exercises were conducted at the Canadian URL in order to test and calibrate their appropriateness for application in excavation design, geologic and hydrogeologic response to excavation or heating, sealing system performance, or mass transport. In many cases back-analysis of experiment results in order to improve numerical model performance provided more value than the conduct of pre-test predictions.

The result of a combination of numerical model development, field testing and calibration of the models has been the development of a wide range of design and performance predictive tools that will be extremely useful in final repository design as well as safety performance assessment.

<u>Yucca Mountain Project Total System Performance Assessment Approach</u>

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The current approach to evaluation long term safety of the total system or its components represents twenty years of scientific information and methodology development. The platform, or executive code, used in the Yucca Mountain Project (part of the new Office of Repository Development), is the Goldsim code developed in cooperation with Golder Associates, Inc. Goldsim provides a flexible platform with the ability to run embedded routines or link in external codes. The nature of the codes linked into Goldsim for the Yucca Mountain application would be different than would be needed to evaluate another geologic disposal system. A few national programs are using Goldsim, most are using other platforms that are tailored to meet their specific needs. Goldsim is discussed in this presentation because it is the platform we use to do safety, uncertainty, importance, and other "what if" type evaluations. The presentation walks through some of the basics of our performance assessment approach and is illustrated using an interactive CD-ROM to be made available to all participants.

The Yucca Mountain Project is writing a license application for submittal to the Nuclear Regulatory Commission in December of 2004. Total system performance assessment is the required means for showing compliance with the regulatory safety criteria in the regulations. Performance assessment by itself is not sufficient to make a case for safety, however. The entire suite of scientific and engineering studies done in support of the long-term safety evaluations must be presented, with discussions of uncertainties and of what additional data is to be obtained to either reduce or more fully understand uncertainties. The regulator will focus on those scientifically evaluated features, events, and processes that are shown by performance assessments to be the more important to determining repository safety. However, in order to judge importance of features, events, and processes, the regulator is not satisfied with believing what has been presented by the Yucca Mountain Project. The regulator has, and exercises, its own system performance assessment capability, and they also study the results of independent evaluations such as those performed by the Electric Power Research Institute. We expect to have a credible license application with a solid basis for a firm expectation of regulatory compliance. That solid basis includes a total system performance assessment that is competently planned and executed, and that is firmly based in the defensible results of two decades' worth of science and engineering studies.

An Overview of the H12 Performance Assessment

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The H12 performance assessment (PA) provided a test for the robustness of a HLW repository system concept based on structured siting and design, taking account of a wide range of potentially suitable Japanese geological environments. The generic nature of the host rock in the H12 assessment means, however, that emphasis is placed very much on strong EBS performance. The assessment included a comprehensive evaluation of uncertainty and potentially detrimental factors, including perturbations due to external events and processes.

Despite the considerable uncertainty at the current stage of the Japanese program, a safety case that is adequate for the aims of the assessment can be made by a strategy of employing conservatism where there is uncertainty and stressing the reliability and effectiveness of the performance of the near-field. The aim of this talk is to present the H12 PA in a way which makes the PA process clearer and the implications of the results more meaningful, both to workers within the PA field and to a wider technical audience.

Total System Performance Assessment: The Disposal of Canada's Nuclear Fuel Waste – Case Studies of Long-Term Safety

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Within the Canadian Nuclear Fuel Waste Management Program the assessment of total system performance leading up to the 1994 EIS hearings identified an extensive series of elements that were necessary for the development of a successful performance assessment. These elements included but were not limited to the following:

Regulatory Guidance

Safety standards

Siting guidelines

Performance criteria

Comprehension of system features, events and processes

Engineered barriers

Geosphere

Biosphere

Scenario identification and treatment

Normal evolution

Altered evolution

Disruptive events

Model development and quality management

Process models

System models

Database development and quality management

Software development and quality management

Computations and analysis

Consequences

Uncertainties

Sensitivities

Compliance with criteria

Mitigative measures

Design constraints

Siting constraints

Documentation of overall assessment

Public audience

Technical audiencePerformance Assessment is an integral part of the decision-making process of a waste disposal project. In order to be appropriate it needs to be integrated with a number of activities including:

Characterization of the natural system

Host rock formation

Accessible environment

Design and testing of the engineered barriers

Waste form

Container

Buffer

Backfill

Seals

Locating and laying out of the access tunnels and disposal rooms

Addressing Issues arising from public consultation

Ensuring of regulatory compliance and licensing

Repository Design and Performance Confirmation

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The design of a repository and confirmation of its performance is a complex task that requires the integration of a large number of activities including, but not limited to: numerical modeling, engineering design, construction, site characteristics and location, as well as development of a monitoring system that can adequately monitor system performance and determine if any safety issues develop.

For a Canadian repository a number of issues will feed into the design process, including:

- Quantity of used fuel in each container (72-420 bundles),
- Quantity of used fuel in the repository (3.6 to 10.1 million bundles),
- The initial heat output from used fuel at time of emplacement,
- The decay characteristics of the fuel,
- Temperature design criterion for container surface (90°C to 100°C),
- The thermal and mechanical properties of surrounding sealing materials and geosphere,
- The thickness of the materials required for sealing and radiation shielding.

Each of these issues can be addressed through the use of field-calibrated models to predict system performance but there is still a need to monitor to confirm that the system is performing as required. In addition the fact that it is a natural system that is being disturbed and engineered to serve as a repository makes it necessary that the basic design adopted be able to deal with a range of general site characteristics to be encountered without compromising the basic design concepts. It must also have the capacity to accept as-built modifications to the repository during construction to allow for site-specific conditions to be engineered and the flexibility to incorporate new information on system performance into the design and construction of the repository.

Monitoring of repository performance will be conducted in two stages, pre-closure and post-closure.

The pre-closure stage of monitoring is intended to:

- Obtain sufficient, accurate and pertinent baseline data so that design requirements for the repository can be met;
- Ensure that regulatory compliance requirements are being met;
- Detect any performance problems with repository systems and components at an early stage so that corrective actions can be taken in a timely manner;
- Develop sufficient confidence in the performance of the implemented repository facility design so regulators and other stakeholders can decide to end the preclosure phase and close the repository.

- The post-closure stage of monitoring is intended to:

- Demonstrate that the repository continues to meet compliance and performance monitoring requirements (i.e., continued design validation).Detect any anomalous behaviour so that remedial actions may be taken as necessary to protect public health and the environment.Allow regulators and other stakeholders to develop confidence in the validity of the implemented repository.

In order to accomplish these goals there is a process of developing and testing the instrumentation and technologies necessary to successfully monitor the repository.

Performance Confirmation

Claudia M. Newbury
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Office of Repository Development
Office of Civilian Radioactive Waste Management|
U.S. Department of Energy

BASIS FOR PERFORMANCE CONFIRMATION

During the operational phase of a repository, a Performance Confirmation (PC) program will be put in place to evaluate whether subsurface conditions are within limits assumed in the license and whether natural and engineered systems are functioning as intended and anticipated. Selection of the components of the program will be based on testing of those barriers that have been identified as important to waste isolation and safety.

The PC program includes in situ monitoring, laboratory and field testing, and in situ experiments, as appropriate. Testing activities should be selected that do not adversely affect performance of the system. The initial information collected as part of the PC program will provide baseline information about the site. As testing continues, the program will monitor and evaluate changes from the baseline.

PROGRAM DEVELOPMENT

Selection of a portfolio of testing and monitoring activities begins by developing evaluation criteria and defining a set of candidate activities. The candidate activities are evaluated by both technical and management reviewers. The selected activities are then placed into candidate "portfolios" defined by such factors as cost effectiveness and focus on in situ activities. The portfolios are then ranked and a set of testing activities is selected for the PC program.

IMPLEMENTATION OF TESTS AND ANALYSES

In fielding tests and setting up monitoring programs, consideration should be given to regulatory reporting requirements, in terms of timing of the test relative to other activities, and the expected level of detail. Periodic evaluations of the test results should look at individual and cumulative effects of repository operations. If results fall outside expected ranges, analyze impacts and report results.

SUMMARY

Define expectations for program. For each barrier identify parameters and candidate testing activities. Define expected bounds for testing results.

EVALUATE AND REPORT RESULTS

Highlights from a Worldwide Review of URLs and Nuclear Waste Disposal Development

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This report presents some highlights from, "Geological Challenges in Radioactive Waste Isolation: Third Worldwide Review" that was published in 2001 by LBNL. One of the important developments in waste isolation activities is the increasing use of an underground research laboratory (URL) for the specialized investigations that are needed. The first URL in granitic rock was started in 1977, when Sweden and United States collaborated in the construction and operation of the Stripa project in an abandoned iron ore mine. In the 1980s, three more pioneering URLs were put in operation. Belgium was the first country to construct a URL in clay. Canada constructed a URL in the Lac du Bonnet granitic batholith in the province of Manitoba, and Switzerland constructed their Grimsel URL in the granitic rocks of the Bernese Alps. Stripa was abandoned in the early 1990s, and Sweden soon had a second URL in operation in granitic rock at Äspö. Details from the wide variety of investigations carried out in these early URLs are discussed. The important benefits derived from such operations generated considerable attention, and as of 2001, there are now 11 countries that are using URLs, or are in various stages of planning and developing such facilities.

This increasing use of URLs has led to another important development, in which two or more countries (or organizations) can contribute to joint projects at a given site in order to carry out an underground research program on problems of mutual interest. For example, in Switzerland, Nagra and 17 other organizations from 9 countries have been carrying out joint research projects at Grimsel. They are now planning a series of new projects to begin at the end of 2003. Nagra is also involved in a second URL, at Mont Terri in the Jura Mountains, where 11 project partners from 6 countries are now involved in their seventh year of joint research projects in the Opalinus Clay. In effect, Nagra and its collaborators have developed an impressive international program for research on problems of nuclear waste isolation.

Problems with public acceptance of the management of nuclear-waste isolation projects have occurred in a few instances. The reaction of the public, especially where deficiencies in the technical and social aspects are revealed, has led to setbacks in waste management projects. In 1997, Nirex in the United Kingdom was refused permission to construct a URL at their Sellafield project, which led to the termination and abandonment of the project. Despite an extensive site-selection procedure, Nagra in Switzerland was unable to get approval for an LILW repository at Wellenberg. Approval was denied in two cantonal votes (1995 and 2002), and Wellenberg has now been abandoned. The finns have developed a successful method of handling this problem. Before any significant commitment to a nuclear facility is made, Finnish law requires the passage of a Decision-in-Principle (DiP) by the government, which must include a municipal approval. In choosing a location for an HLW repository, they had 4 separate sites to assess and followed a lengthy stepwise process over a period of about 15 years. The public was continually kept informed of all aspects of plans and results. When all field work at the 4 sites was completed, the final selection was based on the outcome of an environmental impact assessment conducted in 1997-1999. A critical component of this process was the nature of the interactions with the public during the lengthy site selection process. The final selection was a site at Olkiluoto in the municipality of Eurojoki, which rendered a strong vote of approval for the proposed siting. In December 2000, the Finnish government approved an application for the DiP that had been made, and on May 18, 2001, Parliament ratified the decision. Finland is the first country in Europe to obtain this kind of governmental approval for an HLW repository site.